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## (54) CONTROL SYSTEM FOR AUTONOMOUS DRIVING OF A VEHICLE

(57) A control system (2) for autonomous driving of a vehicle (1) comprises first and second radar sensor devices (3, 3') at a front side of the vehicle such that they look forward, third and fourth radar sensor devices (4, 4') at lateral sides of the vehicle such that they look sideward, fifth and sixths radar sensor devices (5, 5') at the lateral sides of the vehicle such that they look rearward, first and second camera sensor devices (6, 6') at the front side of the vehicle such that they look forward, and third and fourth camera sensor devices (7, 7') at the lateral sides of the vehicle such that they look rearward, wherein the first and second radar sensor devices and the first and second camera sensor devices are respectively configured to be supplied by battery circuits independent from each other such as to be redundant devices.

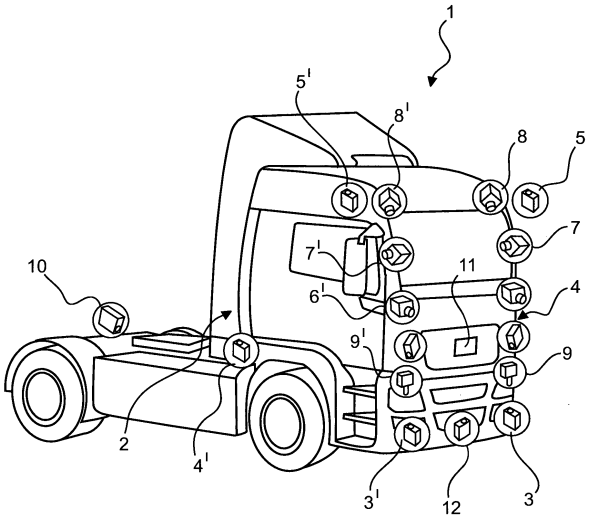


Fig.1

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## Description

**[0001]** The invention relates to a control system for autonomous driving of a vehicle, in particular to a control system for autonomous driving of a transport vehicle, as e.g. a truck and trailer combination.

**[0002]** The autonomous operation of transport vehicles is a new field of inventions. Highly sophisticated functions require high-end hardware infrastructure including different types of sensors and perception technologies. Until now, SAE Automation level 2 systems require presence and attention of a driver. SAE Automation level 3 systems should manage autonomous driving without continuous attention of the driver. In this case, an incident may occur when an element of the system malfunctions or becomes offline.

**[0003]** Until now, in particular in the field of commercial vehicles and trucks, no safe solution or consideration which is able to handle such a situation and which is able to carry out minimal risk safety manoeuvre even after a partial malfunction has been known.

**[0004]** Therefore, the object underlying the invention is to enable a more secure safe-operation of autonomously driving vehicle.

**[0005]** The object is achieved by a control system according to claim 1. Advantageous further developments are included in the dependent claims.

**[0006]** According to an aspect of the invention, a control system for autonomous driving of a vehicle comprises a first radar sensor device attached at a front side of the vehicle such that it looks forward, a second radar sensor device attached at the front side of the vehicle such that it looks forward, a third radar sensor device attached at a first lateral side of the vehicle such that it looks sideward, a fourth radar sensor device attached at a second lateral side of the vehicle such that it looks sideward, a fifth radar sensor device attached at the first lateral side of the vehicle such that it looks rearward, a sixths radar sensor device attached the second lateral side of the vehicle such that it looks rearward, a first camera sensor device attached at the front side of the vehicle such that it looks forward, a second camera sensor device attached at the front side of the vehicle such that it looks forward, a third camera sensor device attached at the first lateral side of the vehicle such that it looks rearward, and a fourth camera sensor device attached at the second lateral side of the vehicle such that it looks rearward, wherein the first radar sensor device and the second radar sensor device are configured to be supplied by battery circuits independent from each other such as to be redundant devices, and the first camera sensor device and the second camera sensor device are configured to be supplied by battery circuits independent from each other such as to be redundant devices.

**[0007]** By such a configuration of the control system, wherein several sensors simultaneously observe a same direction of the vehicle, a redundant environment sensor architecture as a part of a redundant hardware architecture that can fulfil the requirement to carry out minimal risk safety manoeuvre even after a partial malfunction is provided. Based on this idea, main and backup circuits are differentiated with their own power supply sources, and appropriate sensors are doubled into redundant pairs.

**[0008]** In an advantageous implementation of the control system, the third radar sensor device is attached at a lateral driver side of the vehicle such that it looks sideward, at least two fourth radar sensor devices attached at a lateral co-driver side of the vehicle such that they look sideward are provided, the fifth radar sensor device is attached at the lateral driver side of the vehicle such that it looks rearward, and at least two sixth radar sensor devices attached at the lateral co-driver side of the vehicle such that they look rearward are provided, wherein at least one of the at least two fourth radar sensor devices is configured to be supplied by a battery circuit independent from the battery circuit of another one of the at least two fourth radar sensor devices such as to be redundant devices, and at least one of the at least two sixths radar sensor devices is configured to be supplied by a battery circuit independent from the battery circuit of another one of the at least two sixths radar sensor devices such as to be redundant devices.

**[0009]** Compared to the control system according the aspect of the invention, this control system is able to provide an in-lane minimal risk manoeuvre or co-driver side direction lane change minimal risk manoeuver in most of the cases.

**[0010]** In an advantageous implementation of the control system, the control system further comprises a first fisheye lens camera sensor device attached at a first front corner of the vehicle such that it looks downward, and a second fisheye lens camera sensor device attached at a second front corner of the vehicle such that it looks downward.

**[0011]** By providing these camera sensor devices, monitoring and object detection in a direct proximity of the vehicle not covered by front or rear far field sensors is possible.

**[0012]** In an advantageous implementation of the control system, the third camera sensor device is attached at the lateral driver side of the vehicle such that it looks rearward, and at least two fourth camera sensor devices attached at the lateral co-driver side of the vehicle such that they look rearward are provided, the first fisheye lens camera sensor device is attached at a driver side front corner of the vehicle such that it looks downward, and at least two second fisheye lens camera sensor devices attached at a co-driver side front corner of the vehicle such that they look downward are provided, wherein at least one of the at least two fourth camera sensor devices is configured to be supplied by a battery circuit independent from the battery circuit of another one of the at least two fourth camera sensor devices such as to be redundant devices, and at least one of the at least two second fisheye lens camera sensor devices is configured to be

supplied by a battery circuit independent from the battery circuit of another one of the at least two second fisheye lens camera sensor devices such as to be redundant devices.

**[0013]** Du to this configuration, proving an in-lane minimal risk manoeuver or a co-driver side direction lane change minimal risk manoeuver in all cases is possible.

**[0014]** In a further advantageous implementation of the control system, it further comprises a first rotational Lidar sensor device attached at the first lateral side of the vehicle and a second rotational Lidar sensor device attached at the second lateral side of the vehicle, wherein the first rotational Lidar sensor device and the second rotational Lidar sensor device are respectively configured to look sideward and forward.

**[0015]** By these wide angle rotational Lidar sensor devices, in particular at each frontal side of the vehicle, monitoring objects in close proximity at both sides and at the front side, detecting a hazardous object in close proximity with high confidence, and providing a 3 D representation of the surrounding environments are possible.

**[0016]** In another advantageous implementation of the control system, it further comprises three solid state Lidar sensor devices, respectively one solid state Lidar device being attached at the first lateral side, at the front side of the vehicle, and at the second lateral side.

**[0017]** Due to this configuration, monitoring objects in close proximity at both sides and at the front side, detecting a hazardous object in close proximity with high confidence, and providing a 3 D representation of the surrounding environments are also possible.

**[0018]** In a further advantageous implementation of the control system, it further comprises a seventh radar sensor device attached at the vehicle such that it looks rearward below the vehicle.

**[0019]** Because of the provision of this radar sensor device, also the portion of environments directly behind the vehicle can be monitored.

**[0020]** In a further advantageous implementation of the control system, it further comprises an ultrasonic sensor device attached at a front side of the vehicle such that it looks forward.

**[0021]** When providing this ultrasonic sensor device, near field object proximity detection is possible.

**[0022]** In a further advantageous implementation of the control system, it further comprises an eighth radar sensor device and a ninth radar sensor device both being attached to the front side of the vehicle such that they look forward at a wide angle.

**[0023]** By providing these wide angle forward looking radar, detection in a wide field in front of the vehicle is possible especially in bad weather conditions.

**[0024]** In a further advantageous implementation of the control system, the control system is configured to use object information detected by the sensor devices to decelerate or to stop the vehicle, or to execute a lane change with the vehicle, when an object is detected in a specific field of view of the sensor devices.

**[0025]** By this use, autonomous driving of a vehicle even in hazardous situations, is possible.

**[0026]** In the following, the invention is elucidated by means of embodiments referring to the attached drawings.

**[0027]** In particular,

Fig. 1 shows a vehicle including a first embodiment of a control system according to the invention;

Fig. 2 shows fields of view of sensor devices of the control system of Fig. 1;

Fig. 3 shows the vehicle including a second embodiment of the control system;

Fig. 4 shows fields of view of the sensor devices of the control system of Fig. 3;

Fig. 5 shows the vehicle including a third embodiment of the control system; and

Fig. 6 shows fields of view of the sensor devices of the control system of Fig. 5.

**[0028]** **Fig. 1** shows a first embodiment of a vehicle 1 including a control system 2 according to the invention. In this embodiment, the vehicle 1 is a tractor of a trailer truck, however, any appropriate vehicle can be equipped with the control system 2.

**[0029]** The control system 2 is provided with a redundant environment sensor architecture as a part of a redundant hardware architecture. Based on this idea, main circuits including main sensor devices and backup circuits, which are less sophisticated circuits, including backup sensor devices are differentiated. The main sensors provide data that enable the vehicle to drive in an autonomous manner. The backup sensors provide data enabling the vehicle 1 to perform a safety manoeuver and, therefore, the vehicle 1 can perform a necessary safety manoeuver if either circuit fails.

**[0030]** As the main sensors, the control system 2 comprises a first radar sensor device 3 attached at a front side of the vehicle 1 such that it looks forward (FLR), a third radar sensor device 4 attached at a first lateral side of the vehicle 1 such that it looks sideward (SLR) and a fourth radar sensor device 4' attached at a second lateral side of the vehicle 1 such that it looks sideward (SLR), a fifth radar sensor device 5 attached at the first lateral side of the vehicle 1 such that it looks rearward (RLR) and a sixth radar sensor device 5' (RLR) attached at the second lateral side of the vehicle 1 such that it looks rearward, a first camera sensor device 6 attached at the front side of the vehicle 1 such that it looks forward (FLC), a third camera sensor device 7 attached at the first lateral side of the vehicle 1 such that it looks rearward (RLC), and a fourth camera sensor device 7' attached the second lateral side of the vehicle 1 such that it looks rearward (RLC).

**[0031]** Moreover, as backup sensors, the control system 2 comprises a second radar sensor device 3' attached at the front side of the vehicle such that it looks forward (FLR), and a second camera sensor device 6' attached at the front side of the vehicle 1 such that it looks forward (FLC).

**[0032]** The first radar sensor device 3 (FLR) and the second radar sensor device 3' (FLR) are configured to be supplied by battery circuits independent from each other such as to be redundant devices, and the first camera sensor device 6 (FLC) and the second camera sensor device 6' (FLC) are configured to be supplied by battery circuits independent from each other such as to be redundant devices.

**[0033]** Further, the control system 2 comprises a first fisheye lens camera sensor device 8 (DCC) attached at a first front corner of the vehicle 1 such that it looks downward and a second fisheye lens camera sensor device 8' (DCC) attached at a second front corner of the vehicle 1 such that it looks downward. In alternative embodiments, the control system 2 is not provided with the fisheye lens camera sensors 8, 8' or the camera devices are not provided with fisheye lenses but with another suitable sensor.

**[0034]** Furthermore, the control system 2 comprises a first rotational Lidar sensor device 9 (FLL) attached at the first lateral side of the vehicle 1 and a second rotational Lidar sensor device 9' (FLL) attached at the second lateral side of the vehicle 1. In alternative embodiments, the rotational Lidar sensor devices 9, 9' can respectively be replaced by three solid state Lidar sensor devices, respectively being placed at the first lateral side, at the front side of the vehicle, and at the second lateral side. In further alternative embodiments, the Lidar sensor devices can be omitted.

**[0035]** Moreover, the control system 2 is provided with a seventh radar sensor device 10 attached at the vehicle such that it looks rearward below the vehicle.

**[0036]** The control system 2 is also provided with an ultrasonic sensor device 11 attached at a front side of the vehicle 1 such that it looks forward and with an eights radar sensor device 12 attached to the front side of the vehicle such that it looks forward at a wide angle.

**[0037]** **Fig. 2** shows fields of view of the sensor devices of the control system of Fig. 1.

**[0038]** A narrow field FLR (Forward Looking Radar) indicates a fields of view of the first and second radar sensor devices (far field Forward Looking Radar sensor devices) 3, 3' and a broad field FLR indicates a field of view of the eights radar sensor device (wide angle Forward Looking Radar sensor device) 12 for in lane objects detection especially in bad weather conditions.

**[0039]** Fields SLR (Side Looking Radar) indicate fields of view of the third and fourth radar sensor devices (wide angle Side Looking Radar sensor devices) 4, 4' at each side of the vehicle 1 for monitoring and object detection in the neighbouring lanes in the close proximity of the vehicle 1.

**[0040]** Two narrow fields RLR (Rear Looking Radar) indicate fields of view of the fifth and sixth radar sensor devices (far field Rear Looking Radar sensor devices) 5, 5' for monitoring and object detection in the neighbouring lanes in the far field of the vehicle 1, especially in bad weather conditions.

**[0041]** Two fields FLC (Forward Looking Camera) indicate fields of view of the first and second camera sensor devices (far field Forward Looking Camera sensor devices) 6, 6' for detection of lane markings, in lane objects, peer-vehicle detection in surrounding lanes, traffic signs, and road infrastructure elements. The forward looking camera sensor device 6' merely detects lane marking and in lane objects.

**[0042]** Two fields RLC (Rear Looking Camera) indicate fields of view of the third and fourth camera sensor devices (far field Rear Looking Camera sensor devices) 7, 7' for monitoring and object detection in neighbouring lanes in the far field of the vehicle 1.

**[0043]** Two fields DCC (Downward looking Corner Camera) indicate fields of view of the first and second fist eye lens camera sensor device (Downward looking Corner Camera sensor device) 8, 8' for monitoring and object detection in the direct proximity of the vehicle not covered by the front and rear far field sensor fields FLC, FLR, RLC and RLR.

**[0044]** Field MLR (Mid Lower Radar) indicates a field of view of the seventh radar sensor device (Mid Lower Radar sensor device) 10 for coverage of rear field of the vehicle 1 and looking underfloor of the vehicle 1.

**[0045]** Fields FLL (Far Field Lidar) indicate fields of view of the first and second rotational Lidar sensor devices 9, 9' for monitoring objects in near proximity at both sides of the vehicle 1, detecting hazardous objects in near proximity with high confidence, and providing a 3 D representation of the surrounding environments.

**[0046]** **Fig. 3** shows the vehicle 1 including a second embodiment of the control system 2.

**[0047]** The control system 2 of this embodiment has the same main sensors as the embodiment shown in Fig. 1 and Fig. 2. In a backup sensor cluster, third radar sensor device (wide angle Side Looking Radar sensor device) 4 (SLR) is provided at the lateral driver side and, additionally to the embodiment shown in Fig. 1 and Fig. 2, at the co-driver side, the fourth radar sensor device (wide angle Side Looking Radar sensor device) 4' (SLR) is doubled to a further wide angle Side Looking Radar sensor device 4" (+SLR). At the lateral driver side, the fifth radar sensor device (far field Rear Looking Radar sensor device) 5 (RLR) is provided and, at the co-driver side, the sixth radar sensor device (far field Rear Looking Radar sensor device) 5' (RLR) is doubled to a further far field Rear Looking Radar sensor device 5" (+RLR). This provides backup sensor devices for proving an in-lane minimal risk manoeuver or a co-driver side direction lane change minimal risk manoeuver in most of the cases.

**[0048]** **Fig. 4** shows fields of view of the sensor devices of the control system 2 of Fig. 3. In the Fig. 4, except from

the fields of view FLR, FLL, FLC, SLR, DCC, RLC, MLR and RLR already depicted in Fig. 2, additional fields of view "+SLR" and "+RLR" are provided by the redundant sensor devices 4" and 5".

**[0049]** **Fig. 5** shows the vehicle 1 including a third embodiment of the control system 2.

**[0050]** The control system 2 of this embodiment has the same main sensors as the embodiment shown in Fig. 3 and Fig. 4. In a backup sensor cluster, the third camera sensor device (far field rear looking camera sensor device) 7 (RLC) and the first fisheye lens camera sensor device) downward looking corner camera sensor device 8 (DCC) are provided at the lateral driver side of the vehicle 1 and, additionally to the sensor devices 4", 5" of the second embodiment shown in Fig. 3 and Fig. 4, on the co-driver side, the fourth camera sensor device (far field rear looking camera sensor device) 7' (RLC) and the optional second fisheye lens camera sensor device (downward looking corner camera sensor device) 8' (DCC) are doubled to a further far field rear looking camera sensor device 7" (+RLC) and a further downward looking corner camera sensor device 8" (+DCC) as being provided as backup sensor devices for proving an in-lane minimal risk manoeuver or a co-driver side direction lane change minimal risk manoeuver in all cases.

**[0051]** **Fig. 6** shows fields of view of the sensor devices of the control system of Fig. 5.

**[0052]** In the Fig. 6, except from the fields of view FLR, FLL, FLC, SLR, DCC, RLC, MLR and RLR and the additional fields of view "+SLR" and "+RLR" of the second embodiment shown in Fig. 4, additional fields "+RLC" and "+DCC" are provided by the redundant sensor devices 4" and 8".

**[0053]** In use, the present sensor devices capture vehicular environment scene data. The main sensor devices provide first vehicular scene data to a first processing unit for determining first vehicular control data on the basis of the first vehicular scene data for enabling the vehicle to drive in an autonomous manner. The backup sensor devices provide second vehicular scene data to a second processing unit for determining second vehicular control data on the basis of the second vehicular scene data to perform a safety manoeuver.

**[0054]** Although the present invention has been described with reference to specific features and embodiments thereof, it is evident that various modifications and combinations can be made thereto without departing from the spirit and scope of the invention. The specification and drawings are, accordingly, to be regarded simply as an illustration of the invention as defined by the appended claims, and are contemplated to cover any and all modifications, variations combinations or equivalents that fall within the scope of the present invention.

REFERENCE SIGN LIST

**[0055]**

| | |
|---|---|
| 1 | vehicle |
| 2 | control system |
| 3 | first radar sensor device (FLR) |
| 3' | second radar sensor device (FLR) |
| 4 | third radar sensor device (SLR) |
| 4' | fourth radar sensor device (SLR) |
| 4" | double of fourth radar sensor device (+SLR) |
| 5 | fifth radar sensor device (RLR) |
| 5' | sixths radar sensor device (RLR) |
| 5" | double of sixth radar sensor device (+RLR) |
| 6 | first camera sensor device (FLC) |
| 6' | second camera sensor device (FLC) |
| 7 | third camera sensor device (RLC) |
| 7' | fourth camera sensor device (RLC) |
| 7" | double of fourth camera sensor device (+RLC) |
| 8 | first fisheye lens camera sensor device (DCC) |
| 8' | second fisheye lens camera sensor device (DCC) |
| 8" | double of second fisheye lens camera sensor device (+DCC) |
| 9 | first rotational Lidar sensor device (FLL) |
| 9' | second rotational Lidar sensor device (FLL) |
| 10 | seventh radar sensor device (MLR) |
| 11 | ultrasonic sensor device |
| 12 | eights radar sensor device |

## Claims

**1.** A control system (2) for autonomous driving of a vehicle (1), comprising
a first radar sensor device (3) attached at a front side of the vehicle (1) such that it looks forward,
a second radar sensor device (3') attached at the front side of the vehicle (1) such that it looks forward,
a third radar sensor device (4) attached at a first lateral side of the vehicle (1) such that it looks sideward,
a fourth radar sensor device (4') attached at a second lateral side of the vehicle (1) such that it looks sideward,
a fifth radar sensor device (5) attached at the first lateral side of the vehicle (1) such that it looks rearward,
a sixth radar sensor device (5') attached at the second lateral side of the vehicle (1) such that it looks rearward,
a first camera sensor device (6) attached at the front side of the vehicle (1) such that it looks forward,
a second camera sensor device (6') attached at the front side of the vehicle (1) such that it looks forward,
a third camera sensor device (7) attached at the first lateral side of the vehicle (1) such that it looks rearward, and
a fourth camera sensor device (7') attached at the second lateral side of the vehicle (1) such that it looks rearward, wherein
the first radar sensor device (3) and the second radar sensor device (3') are configured to be supplied by battery circuits independent from each other such

as to be redundant devices, and
the first camera sensor device (6) and the second camera sensor device (6') are configured to be supplied by battery circuits independent from each other such as to be redundant devices.

**2.** The control system (2) according to claim 1, wherein
the third radar sensor device (4) is attached at a lateral driver side of the vehicle (1) such that it looks sideward,
at least two fourth radar sensor devices (4', 4") attached at a lateral co-driver side of the vehicle (1) such that they look sideward are provided,
the fifth radar sensor device (5) is attached at the lateral driver side of the vehicle such that it looks rearward,
at least two sixth radar sensor devices (5', 5") attached at the lateral co-driver side of the vehicle (1) such that they look rearward are provided, wherein
at least one of the at least two fourth radar sensor devices (4', 4") is configured to be supplied by a battery circuit independent from the battery circuit of another one of the at least two fourth radar sensor devices (4', 4") such as to be redundant devices,
at least one of the at least two sixths radar sensor devices (5', 5") is configured to be supplied by a battery circuit independent from the battery circuit of another one of the at least two sixths radar sensor devices (5', 5") such as to be redundant devices.

**3.** The control system (2) of claim 1 or 2, further comprising
a first fisheye lens camera sensor device (8) attached at a first front corner of the vehicle (1) such that it looks downward, and
a second fisheye lens camera sensor device (8') attached at a second front corner of the vehicle (1) such that it looks downward.

**4.** The control system (2) of claim 3, wherein
the third camera sensor device (7) is attached at the lateral driver side of the vehicle (1) such that it looks rearward, and
at least two fourth camera sensor devices (7', 7") attached at the lateral co-driver side of the vehicle (1) such that they look rearward are provided,
the first fisheye lens camera sensor device (8) is attached at a driver side front corner of the vehicle (1) such that it looks downward, and
at least two second fisheye lens camera sensor devices (8', 8") attached at a co-driver side front corner of the vehicle (1) such that they look downward are provided, wherein
at least one of the at least two fourth camera sensor devices (7', 7") is configured to be supplied by a battery circuit independent from the battery circuit of another one of the at least two fourth camera sensor devices (7', 7") such as to be redundant devices, and
at least one of the at least two second fisheye lens camera sensor devices (8', 8") is configured to be supplied by a battery circuit independent from the battery circuit of another one of the at least two second fisheye lens camera sensor devices (8', 8") such as to be redundant devices.

**5.** The control system (2) of anyone of the preceding claims, further comprising
a first rotational Lidar sensor device (9) attached at the first lateral side of the vehicle (1), and
a second rotational Lidar sensor device (9') attached at the second lateral side of the vehicle (1), wherein
the first rotational Lidar sensor device (9) and the second rotational Lidar sensor device (9') are respectively configured to look sideward and forward.

**6.** The control system (2) of anyone of claims 1 to 4, further comprising
three solid state Lidar sensor devices, respectively one solid state Lidar device being attached at the first lateral side, at the front side of the vehicle (1), and at the second lateral side.

**7.** The control system (2) of anyone of the preceding claims, further comprising
a seventh radar sensor device (10) attached at the vehicle (1) such that it looks rearward below the vehicle (1).

**8.** The control system (2) of anyone of the preceding claims, further comprising
an ultrasonic sensor (11) device attached at a front side of the vehicle (1) such that it looks forward.

**9.** The control system (2) of anyone of the preceding claims, further comprising
an eighth radar sensor device (12) attached to the front side of the vehicle (1) such that it looks forward at a wide angle.

**10.** The control system (2) of anyone of the preceding claims, wherein
the control system (2) is configured to use object information detected by the sensor devices (3 to 12) to decelerate or to stop the vehicle (1), or to execute a lane change with the vehicle (1), when an object is detected in a specific field of view of the sensor devices.

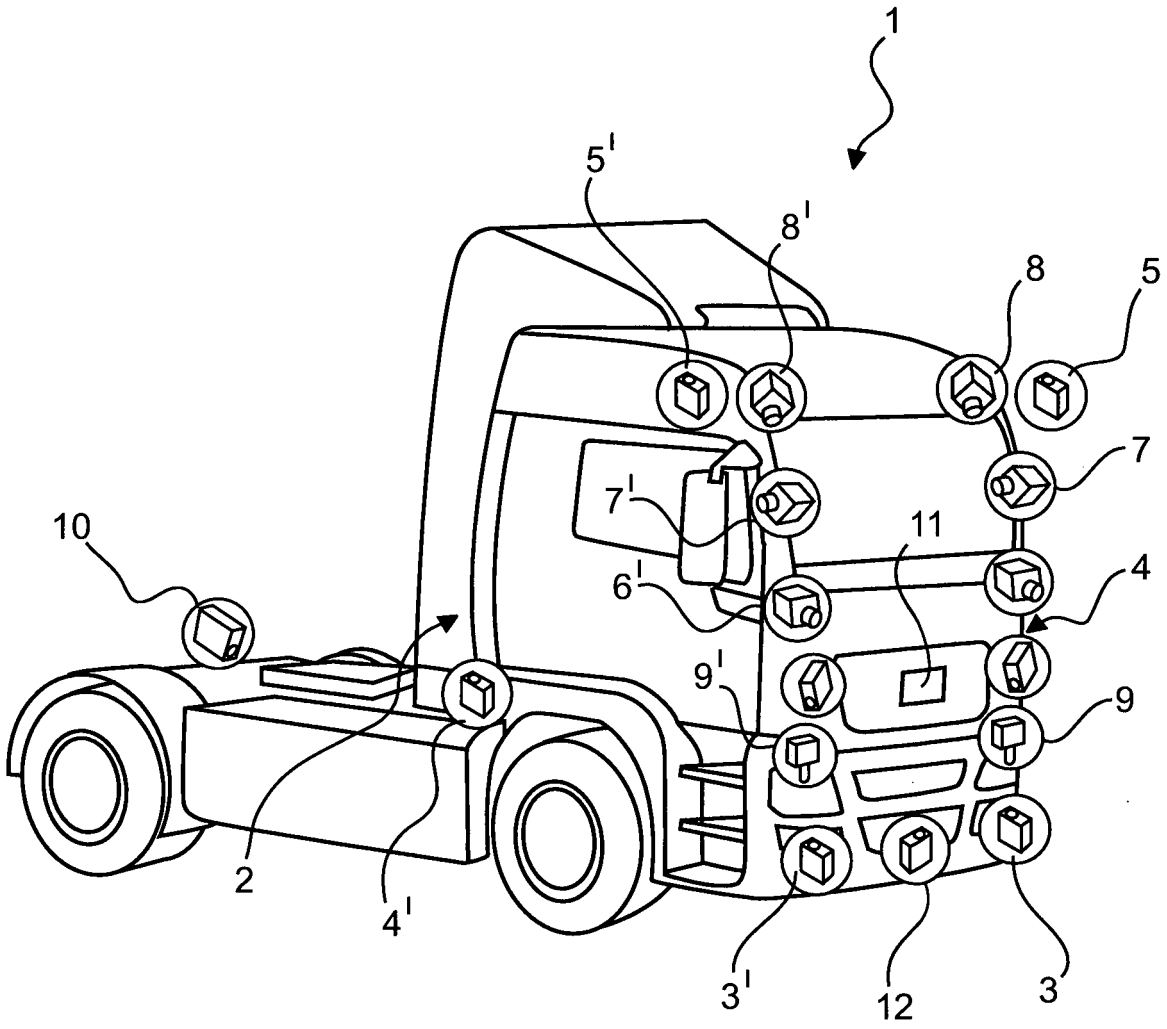



Fig.1

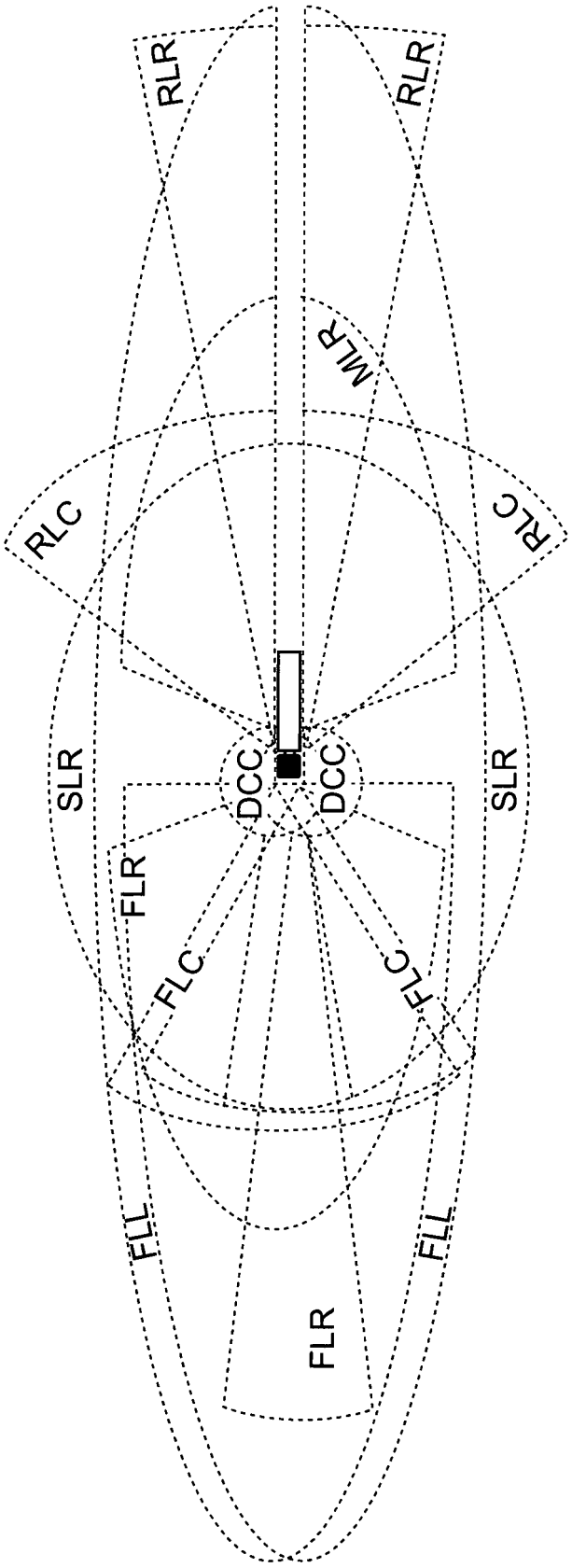



Fig.2

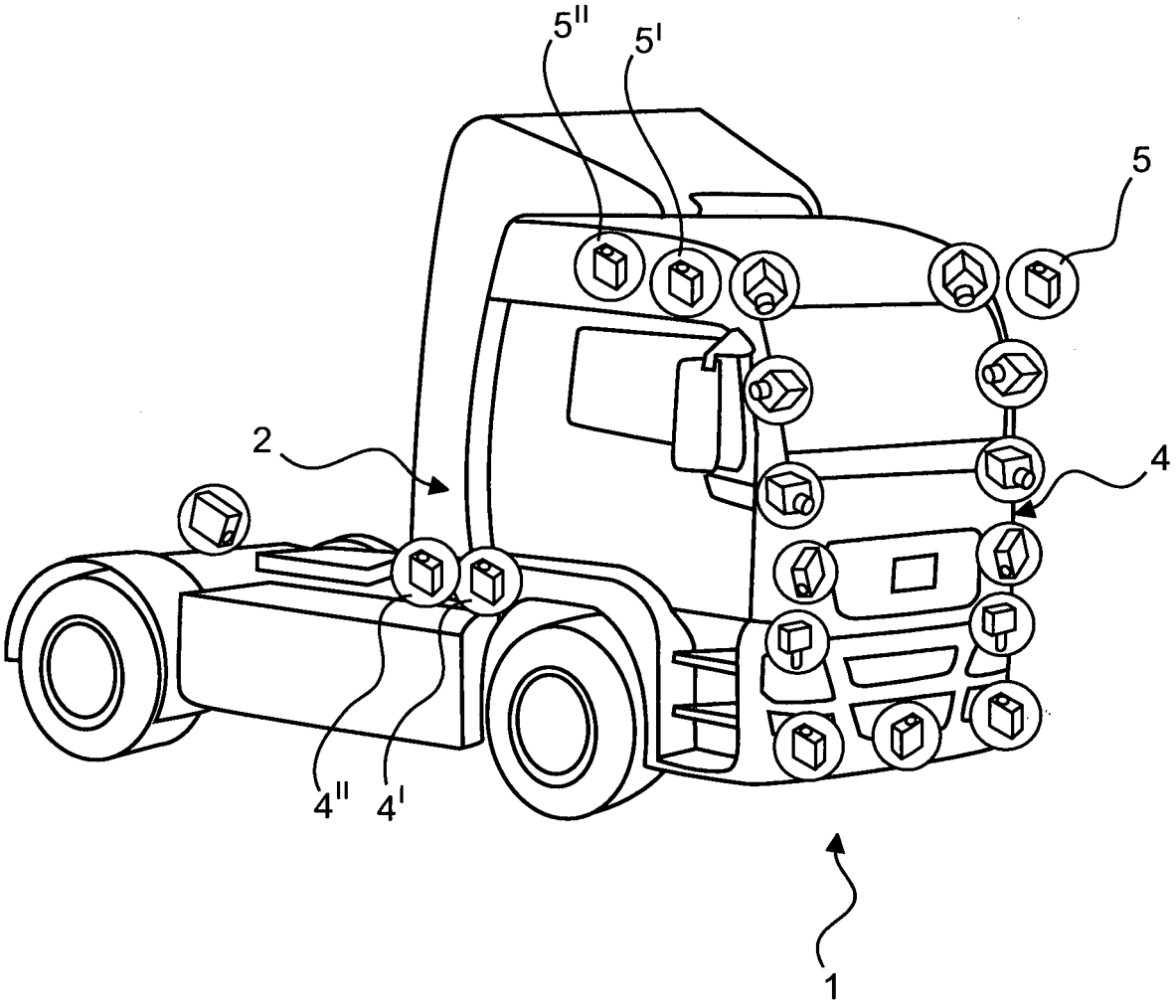
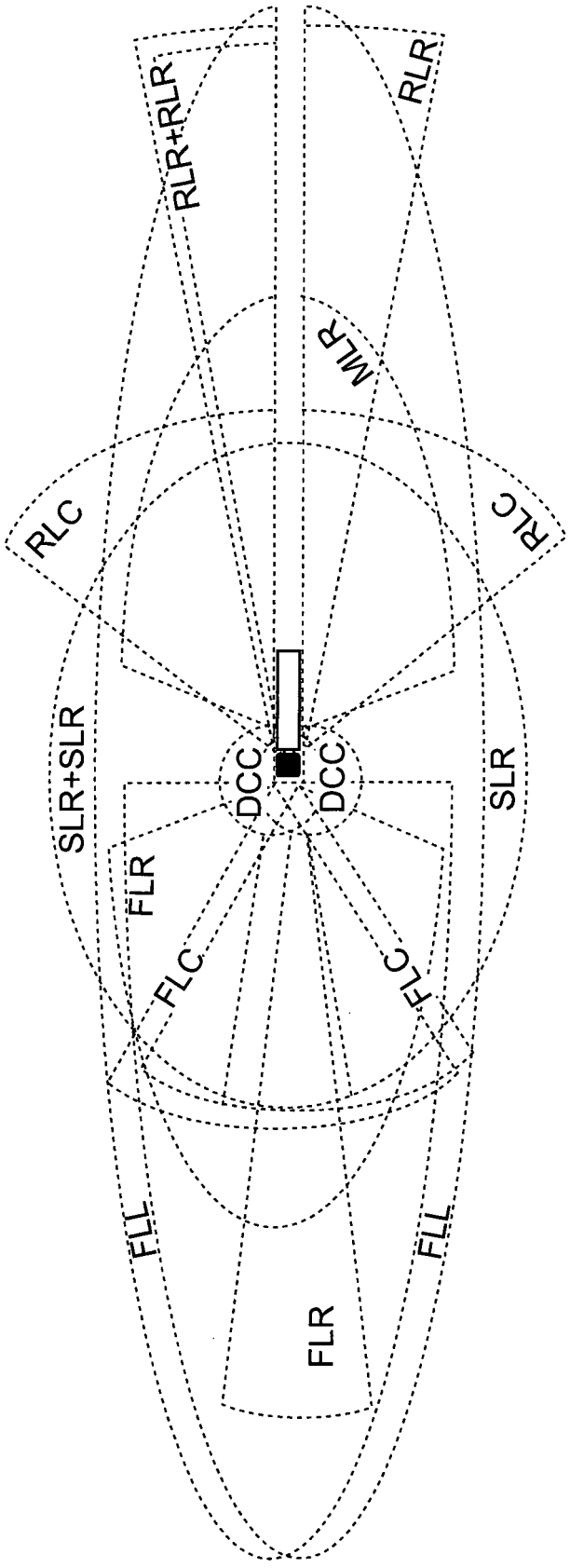



Fig.3


RLR+RLR
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MLR
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SLR+SLR
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Fig.4

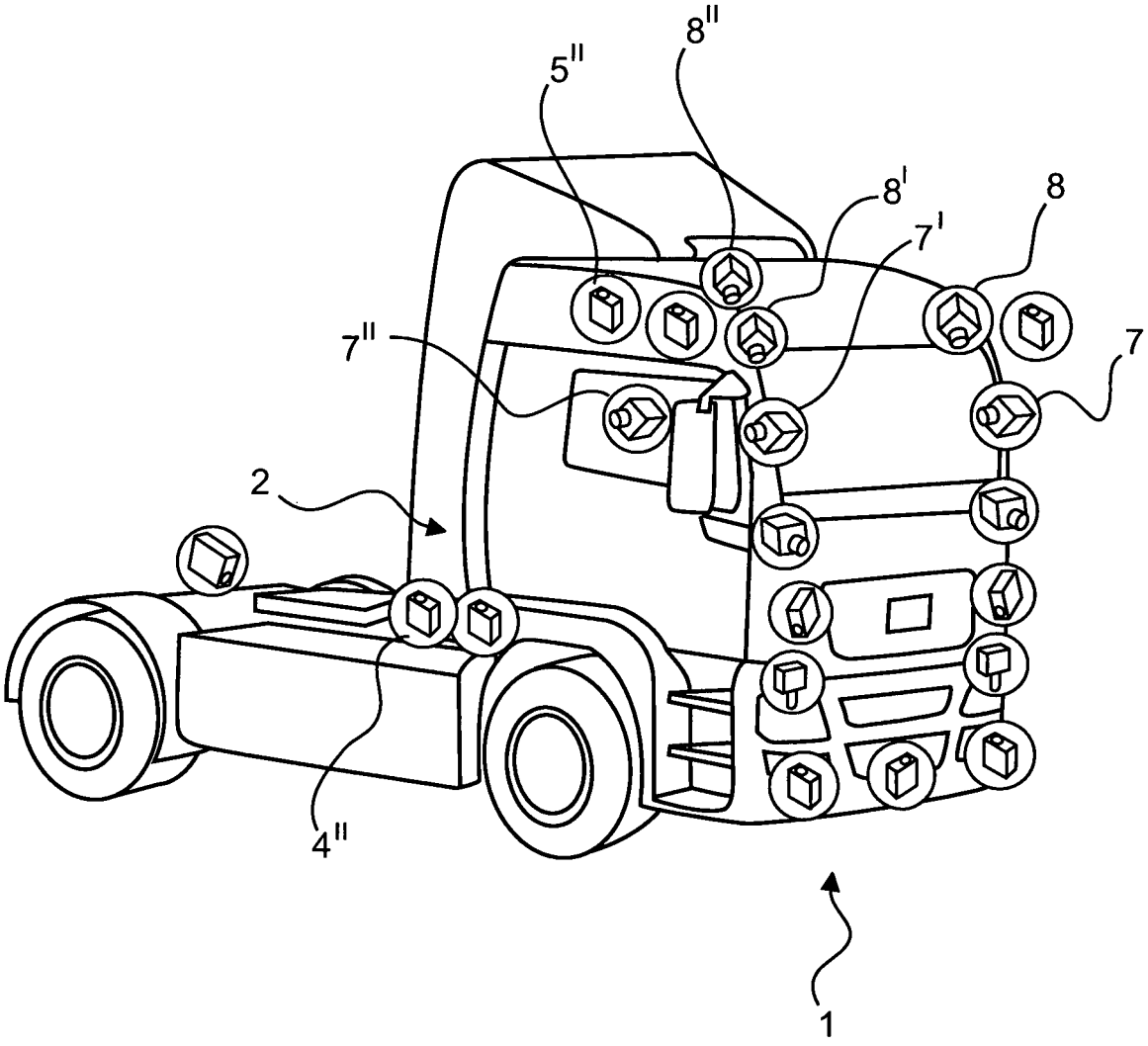


Fig.5

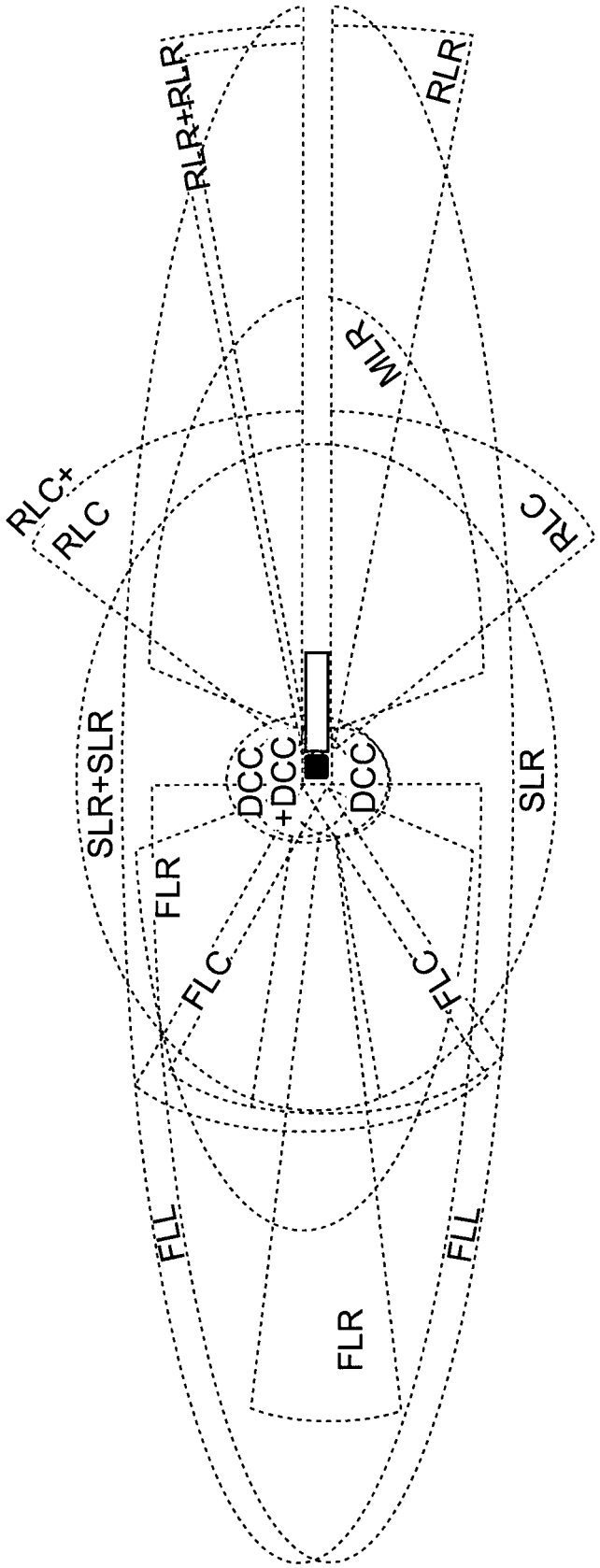
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Fig.6

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# EUROPEAN SEARCH REPORT

Application Number
EP 18 19 5247

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
|---|---|---|---|
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